Chemical Engineering at . . .
Lafayette College

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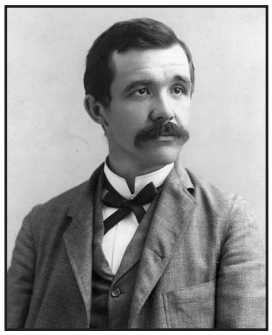
Lafayette College is a small, private college located in Easton, Pennsylvania. It enrolls approximately 2,400 undergraduate students, about half of whom are engineering and science majors. Founded in 1826, Lafayette enjoys a unique connection between liberal arts and engineering; a strategic combination that meets the increased demand for science and technology as well as providing the creativity and insight imparted by the arts and humanities.

In addition to its strong tradition of liberal arts and engineering, Lafayette College is also known for its longstanding football rivalry; we hosted the 150th meeting of Lafayette and Lehigh at Yankee Stadium in November 2014. Begun in 1884, Lafayette-Lehigh is the nation's most-played college football rivalry, and it has been played every year since 1897 without interruption—the longest streak of consecutive years for any rivalry in college football.

The 150th also marked the kick-off of the capital campaign, *Live Connected, Lead Change*, celebrating the accomplishments of the college and its alumni. The college is enabled by an endowment-per-student in the top eight percent of all colleges and universities in the country, Lafayette has a strong record of achievement in the chemical industries with distinguished alumni including John Townsend Baker (founder, J.T. Baker Chemical), Alvin and Andy Deitz (founders, Spectra Gases), and Stephen D. Pryor (CEO, ExxonMobil Chemical). This alumni base coupled with the strong relationships with industry leaders ExxonMobil, Air Products, DuPont, BASF, GlaxoSmithKline, and Merck and Company enable Lafayette chemical engineers to routinely secure post-graduation job placement in these companies, as well in programs for advanced study. In the last five years, graduates have enrolled in programs at Princeton, Johns Hopkins, Cornell, the University of California–Santa Barbara, and the University of Delaware, among others. Since 2010, five Lafayette chemical engineers have been awarded National Science Foundation Graduate Research Fellowships, and eight since 2003. In a study recently reported by PayScale.com, Lafayette boasts a seven percent annual return on investment over 20 years; it is ranked 8th among liberal arts colleges in the nation.

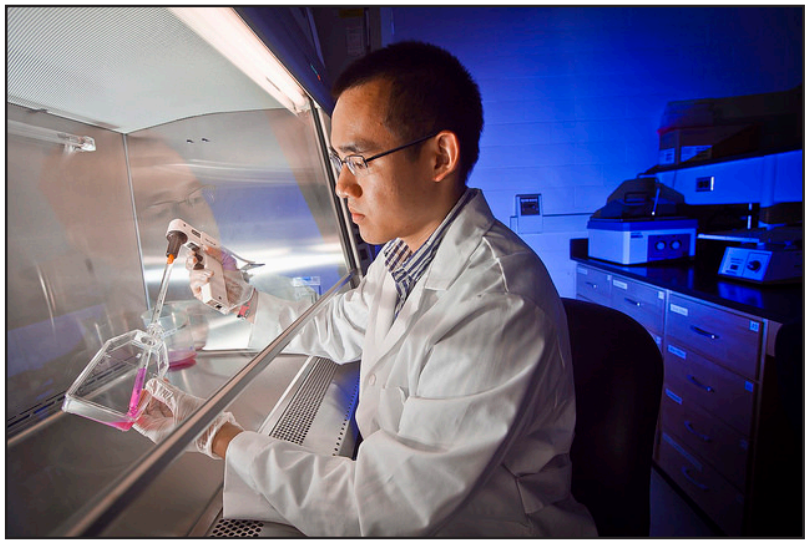


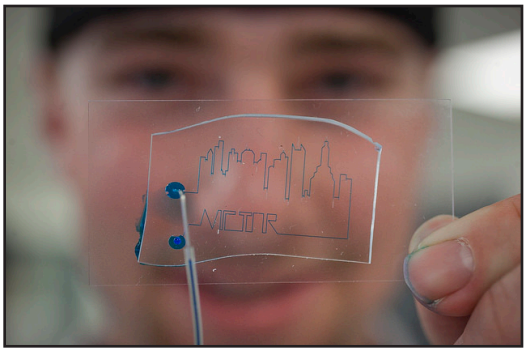
In 2016, engineering at Lafayette will celebrate 150 years; chemical engineering at Lafayette is celebrating its centennial in 2015.

THE HISTORY OF ChE AT LAFAYETTE

The origin of chemical engineering at Lafayette can be traced to Dr. Edward Hart. Hart received his Ph.D. in chemistry from the Johns Hopkins University in 1878, studying with Dr. Ira Remsen. Joining the faculty of the chemistry department at Lafayette shortly thereafter, Hart immediately began inspiring students to pursue opportunities in chemical manufacturing. Together with John Townsend Baker (B.S., Chemistry, 1882; M.S., Chemistry, 1885), Hart founded the partnership of

Top, above: *Edward Hart, co-founder of Baker and Hart Chemical and the founder and editor of Analytical Chemistry. Hart was the chair of the Industrial and Engineering Chemistry Division of the American Chemical Society and department head of chemistry before becoming the first professor of chemical engineering at Lafayette College.*
Bottom, above: *Eugene C. Bingham, co-founder of the field of rheology and author of Fluidity and Plasticity (McGraw-Hill; New York, NY). Bingham was the organizer of the first Plasticity Symposia of the American Chemical Society. He was head of chemistry at Lafayette College.*



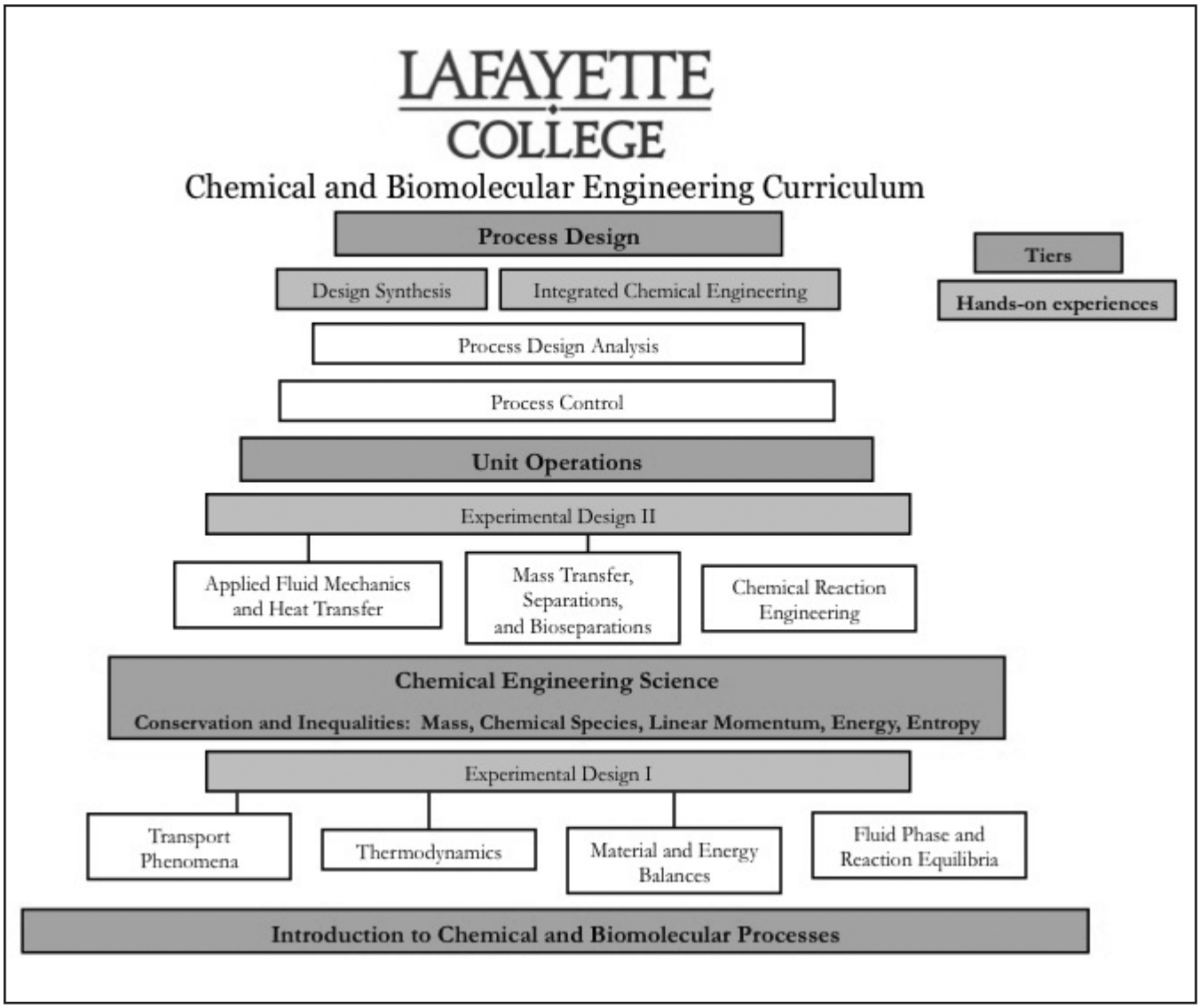


Top: *The Inaugural Chemical Engineering Spring Symposium included commissioning and ribbon-cutting ceremony of the twin-column distillation plant in the Lafayette Unit Operation Laboratory by Stephen D. Pryor, CEO, ExxonMobil Chemical.*

Left above: *Kevin Ling explores experiential molecular bioengineering in the LafChBE Tissue Cultural Facility (2012).*

Right above: *Student Victor D'Ascenzo, class of 2017, made a name for himself—literally— in Lafayette's Introduction to Engineering/ChBE module, which teaches the art of engineering small/microfluidic device fabrication.*

Baker and Hart in 1882, and began the production of refined chemicals in a small plant that they constructed together on College Hill, several blocks from campus. In 1884, another of Hart's students, George Purseglove Adamson (B.S., chemistry, 1884; M.S., chemistry, 1887) joined their partnership,



The Chemical and Biomolecular Engineering (ChBE) curriculum at Lafayette College: hierarchical organization.

which then became known as the Baker and Adamson Chemical Company. It was reckoned that Hart's name was omitted from the enterprise because Lafayette College preferred that the business activities of its staff remained unpublicized. Nonetheless, Hart served as president of Baker and Adamson Chemical from its incorporation in 1890 until 1913. Revenues in 1890 were $10,000 per month! (*The Octagon*, May 1960, Vol. 43, No. 5)

Another of Hart's students was Richard Kidder Meade (B.S., chemistry, 1899; M.S., chemistry, 1908). Meade founded and edited *The Chemical Engineer*, a journal of practical, applied, and analytical chemistry. Perhaps most noteworthy, in a forceful editorial first published in October 1905 and re-printed in October 1907, titled "Why not 'The American Society of Chemical Engineers'?" Meade argued that "…mining, civil, electrical, and mechanical engineers are organized and each has a strong society … the chemical engineers must also organize and the time is now opportune for the formation of an American Society of Chemical Engineers." (*The Chemical Engineer*, Volume 3, 1905) A committee of six, including Arthur D. Little, William H. Walker, and Richard Meade, was formed to explore the need for such a society, and the American Institute of Chemical Engineers was established in January 1908. Among the 40 charter members, George Adamson was a member of the Council of the Institute from 1908 until 1911. Also a charter member of the AIChE, Hart served on the council from 1911 through 1913. The first Finance Committee was comprised of Hart, Adamson, and Meade, while Hart was also a member of the publications committee. (Volume 1, *Transactions of the American Institute of Chemical Engineers*, 1908) It is significant that these Lafayette chemists were at the forefront of the movement to organize the AIChE and took such an active part in its early life.

At Lafayette, the college catalog for academic year 1915–1916 first listed a "Course of Study in Chemical Engineering" in the summer of 1915. In the following year, Hart stepped down as head of the Department of Chemistry to become the first professor of the chemical engineering at Lafayette; he was succeeded by Dr. Eugene C. Bingham, also an industrial chemist.

The first students of the chemical engineering course of study at Lafayette graduated in 1919. The B.S. in chemical engineering was first conferred at Lafayette in 1920. In 1921 Hart published the first textbook in the United States to bear the title *Chemical Engineering* (Chemical Publishing Company; Easton, Pa.).

As the Program in Chemical Engineering grew, the tradition of industrial chemistry was strong at Lafayette under Bingham in the 1920s. His milestone text, *Fluidity and Plasticity* (McGraw-Hill; New York, NY) in 1922, first described his observations that certain fluids did not flow until the imposed shearing stress reached a critical value, the yield stress, τ_0. The first and third Plasticity Symposia of the American Chemical Society were hosted at Lafayette in 1924 and 1928, the latter of which spawned the Society of Rheology, organized in April 1929 in Columbus, Ohio. Leveraging the connection between the humanities and science and technology, the term "rheology" was coined at Lafayette by a classics professor at the request of Bingham and Marcus Reiner, then frequent visiting scientist, to make the subject more approachable.

An independent Department of Chemical Engineering was established in 1938. From 1938 through 1961, chemical engineering was led by Dr. E. L. McMillan. During this time, a student section of the AIChE was established (1940) and the program was first accredited (1956). Other major milestones in the department include its merger with the Department of Metallurgical Engineering in 1976; the closure of Metallurgical Engineering as a program in 1990; and the expansion of the department to include biomolecular engineering in 2008. Presently, the department maintains nine faculty positions and has more than 150 undergraduates across all class years—the fourth-largest degree program at Lafayette.

CURRICULUM

Chemical engineers bridge from the molecular sciences to the consumer through the creation and optimization of value-added processes and products. The curriculum in the Department of Chemical and Biomolecular Engineering (ChBE) at Lafayette seeks to train undergraduates to not only traverse this bridge, but ultimately provide its foundation. As such, the plenary curriculum is organized into four hierarchical levels: Introduction to Chemical and Biomolecular Processes, Chemical Engineering Science, Unit Operations, and Process Design. Additionally, the curriculum provides flexibility for all ChBE students to fully participate in the Common Course of Study (CCS) at Lafayette College.

Experiential learning

Experiential learning is, and always has been, one of the hallmarks of chemical engineering education at Lafayette College. Students at Lafayette have been attracted to the notion of applying concept to practice since the days of Edward Hart. In the 1970s, Dr. George M. Hoerner, then associate professor of chemical engineering, convened 33-hour (voluntary!) laboratory sessions focusing on continuous manufacturing of solvent-based products in the Unit Operations Laboratory. Shifts began on Friday at 1 p.m. and continued through 10 p.m. on Saturday with operators (the inexperienced students) and crew chiefs (seniors with previous operating experience), while the shift supervisor, Dr. Hoerner, was on-hand the entire time with his sleeping bag in a room across the hall.

Currently, we seek to elaborate the complementary nature of theory and practice in our Experimental Design I (CHE312), Experimental Design II (CHE322), and Integrated Chemical Engineering (CHE412) hierarchy. This three-course sequence is composed of hybrid courses that emphasize experiential learning, increasing complexity from the bench to the unit operation to the pilot plant scale.

Experimental Design I (ED1) focuses on thermophysical properties characterization, such as viscometry, rheometry, diffusion, and calorimetry. In addition to illustrative lab experiences that utilize a range of bench scale equipment, students are exposed to lectures in the systematic empirical approach of statistical design of experiments (DOE). In ED1, emphasis is placed on full-factorial DOE together with both descriptive and inferential statistical tools enabling students to parameterize and characterize highly coupled complex chemical systems. There is also a focus on integrating laboratory and writing skill through reports and both oral and poster style presentations.

Experimental Design II (ED2) focuses on the unit operations of chemical engineering, such as fluid and heat transfer and multiphase flow, fluid phase equilibrium, and an introduction to feedback controlled processes. In ED2, lectures on statistical design of experiments are continued with an emphasis on fraction factorial and central composite design of experiments. The communications emphasis shifts to memo-style results reporting and continues to build on oral presentation skills.

Integrated Chemical Engineering (ICE) focuses on integrated pilot and industrial scale processes, such as continuous gas absorption, stripping, liquid-liquid extraction, distillation, and reverse osmosis, as well as experiments demonstrating dynamic interacting systems reactors in series, bioreactor mass transfer and kinetics, and advanced manufacturing processes. In ICE, student learn approaches to safety and hazards analysis; working in teams, all students complete and document Hazards and Operability Studies (HazOp) for a process. Students are assessed on full laboratory and HazOp reports, and oral presentations on advanced topics

in the chemical process industry such as statistical process control; environmental, health, and safety regulations; risk; and compliance.

Pedagogical innovation takes the form of flipped laboratories to empower students to personally control hands-on learning with the overarching goal to enhance student understanding and operability of chemical engineering processes and equipment. A flipped laboratory is a pedagogical model that essentially inverts the instructor-to-student passage of information regarding operation of key pieces of equipment. Students have access to a library of short videos that explain standard operating procedures, common protocols, and troubleshooting tips. Students watch the videos for pre-lab assignments and can have access to the video protocols with them in the laboratory using tablet-style devices.

The LafayetteChBE YouTube channel (<https://www.youtube.com/user/LafayetteChBE>) hosts short tutorial videos for each major piece of equipment focusing on SOPs, quick start and instrument familiarity, and troubleshooting guides. Students and faculty can access these videos and learn how to operate the equipment. With over 40,000 views on these videos, based on an average in-class laboratory class size, we are demonstrating impact well beyond our institution.

Capstone design

Capstone design is a highlight of the student experience in ChBE through the diversity of projects offered. In 2015 projects feature industry/academy partnerships in conductive plastic process development and characterization in cooperation with Zzyzx Polymers and full-density digital part materialization through additive manufacturing with the ExOne Company. In these projects, students are involved and receive first-hand perspectives to the challenges and rewards associated with innovation and entrepreneurship in start-up enterprises.

Specializations and electives

The breadth in ChBE technical electives within the department enables wide exposure to chemical engineering subdisciplines. We have created speciality hybrid courses across several sub-disciplines including materials and interfaces, micro and nanofabrication, molecular bioengineering, and energy and the environment.

One example, CHE 344 Interfacial Phenomena, is an elective course that includes topics such as the thermodynamics of surfaces and interfaces, adhesion, intermolecular forces, DLVO theory, electrostatic and electrokinetic effects in colloidal systems, and characterization techniques such as scanning force microscopy, light scattering, and microscopy. The course is approximately evenly divided between lectures, lab experiences, and seminars in current literature. We use seminar and laboratory experiences as didactic opportunities to train students in lifelong learning methods. For each weekly two-hour seminar or lab experience, self-selected student groups identify a topic or method from a list of 15 or so subjects designed to complement the lectures. Each group of three or four is mentored to develop a hosting strategy to engage the rest of the class in a meaningful experience. For seminars, this means selecting (and learning how to select) current literature and developing study/discussion questions for the class by serial jury-like selection of articles. For laboratory experiences, this means setting up rotating stations that enable all students in the course to learn sophisticated research techniques such as dynamic light scattering and zeta potential measurement, axisymmetric drop shape analysis, confocal microscopy, and scanning force microscopy while simultaneously mitigating the risks associated with new users and expensive equipment by pre-training the hosting group.

The feedback we have received from both students and faculty at Lafayette and in national venues, such as the American Society for Engineering Education (ASEE), has been highly positive suggesting that our approach would be well received in a variety of other venues.

Individualized learning

Lafayette ChBE faculty are active in diverse contemporary research areas such as energy and the environment, materials and interfaces, micro and nanofabrication, molecular bioengineering, and pedagogical innovation.

The eight faculty in the department during the last four years have published more than 30 peer-reviewed journal publications—many including student co-authors—and garnered more than $2M in federally funded research grants while hosting more than 100 individual student experiences.

At Lafayette, individualized learning opportunities take on many different forms. Students can participate in the Lafayette EXCEL Scholars Program, which enables high-performing students to assist faculty members with their scholarship. The purpose of the EXCEL Program is to encourage collaboration in learning between faculty and students. The work of the student must, therefore, be research-oriented and not clerical in its primary emphasis. Faculty members supervising EXCEL Scholars receive assistance in accelerating the progress of their research efforts. Students can also undertake research for credit. The department permits one semester of student research toward the chemical engineering elective requirements. The highest achieving students often choose to undertake a two-semester senior honors thesis in order to earn departmental honors. These students are supervised or co-supervised by department faculty.

FACILITIES AND EQUIPMENT

In 1938, the department was granted an initial fund of $10,000 provided by the Trustees of the College to equip the Chemical Engineering Laboratory. Much of the equipment was designed and installed by senior chemical engineer-

ing students and Dr. McMillen, including heat transfer, filtration, fluid flow, drying, air conditioning, and gas absorption. The utilization of students in the construction of simpler laboratory units enabled most of the funds to be used to purchase commercial pilot scale equipment units for distillation, evaporation, and continuous vacuum filtration.

Since 2010, the department has acquired new capital assets (~$1.7M) associated with experiential learning through new state-of-the-art instrumentation and equipment to help us maintain our standing as one of the premier locations for undergraduate education including an additive manufacturing suite featuring a ProMetal 3D printer that enhances the capstone design sequence; a new Custom Separations Technologies independently operated twin-column distillation plant featuring digital controls that enhances experimental design and integrated chemical engineering courses; a micro/nanofabrication laboratory featuring photo and soft lithography as well as a scanning electron microscope that has been integrated into our first-year engineering design experiences; and a Center for Molecular Bioengineering enabled by a Nikon Eclipse Ti-E inverted microscope with C1 Plus confocal imaging system, a biaxial micromaterials mechanical test frame, and many tools from molecular biology helping to meet the growing demand for student experiences in molecular bioengineering.

Assistant Professor Lindsay Soh and students participate in Introduction to Engineering/LafChBE: renewable biofuel and the global energy challenge.

CO-CURRICULAR PROGRAMS

In collaboration with the department, the Lafayette Chapter of the American Institute of Chemical Engineers (AIChE) has helped in the development of upcoming professional chemical engineers through out-of-class academic enrichment, student-faculty interaction, and career path support. This co-curricular program of student engagement includes many outward facing programs such as informal lunchtime talks to inform students on opportunities within Lafayette's chemical engineering department including course scheduling, study-abroad, and research opportunities. Seminars also include presentations by professionals to help students explore career opportunities in chemical engineering and advanced industrial concepts that have not been extensively covered in curriculum. The department and AIChE Student Chapter also host regular networking and social events to facilitate student, faculty, and alumni interactions. This programming is complemented by specific events including off-campus trips, participation in college-wide events, and outreach opportunities. There are about 30 programmed events per year.

In March 2014, the department and the Lafayette AIChE Student Chapter hosted the inaugural Chemical Engineering Spring Symposium, "Engineering re-Connections: Framing Future Networks" featuring a celebration of the commissioning of the new twin-column distillation plant—bringing together more than 150 students, faculty, and alumni with representatives from 11 different companies including ExxonMobil, Pinnacle Foods, Air Products and Chemicals, AstraZeneca, BASF, Dow, and O'Brien & Gere.

STUDENTS AND ALUMNI

In 1919, there were six graduates of the Chemical Engineering Program. After the separate department was established in 1938, enrollments grew—and in 1959, it was reported that the freshman enrollment numbered 43 students, with "many of the abler men entering the College among this group." (Annual Report of the Department of Chemical Engineering, 1959-1960).

Lafayette chemical engineers have always been engaged in campus life and extra-curricular activities. In academic year 1967-1968, Lafayette was the host for the AIChE Student Conclave. Two papers were read by Lafayette seniors, and William Flis received honorable mention for his presentation. The annual report of the department recorded: "In what

is becoming almost typical for Lafayette's scholar-athletes, [Flis] accomplished this by entering the MAC Track Meet preliminary time trials at the University of Delaware on Friday afternoon, presenting his paper to the conclave in Easton on Saturday morning, and returning to Delaware for the balance of the track meet later this Saturday."

The trend of scholar-athletes has continued across the years. David Klaus, a chemical engineer, was the captain of the Lafayette basketball team that won the Patriot League tournament in 1999 and went on to play in the NCAA Tournament. The Lafayette record for receiving yardage in football, set by John Weyrauch in 2003, stood for nearly a decade. Athletics, however, is only one of many extra-curricular activities undertaken by ChBEs.

Due to the strong mentorship from ChBE faculty, many Lafayette students have placed in the AIChE Mid-Atlantic Student Research Paper competition, including Daniel Connolly and Tyler Fruneaux who went on to the national competition in 2002 and 2014, respectively.

The bond between faculty and students has also been a constant. During the civil unrest in the late 1960s, Department Head Zbigniew D. Jastrzebski recorded, "although the academic year has witnessed considerable unrest and some demonstrations on the Lafayette campus, our chemical engineering students … are in close personal contact with their professors so that the spirit of comradeship between faculty and students is well-developed." The same is true today; chemical engineering faculty plan, prepare, and host a midnight breakfast for students in the department once each semester.

Between 1919 and 1938, there were 120 graduates of the chemical engineering program. The total number of undergraduate students has ranged from as few as six in 1919 to 144 in 2014. On average 66 percent of ChBE students study abroad, while staying on track for graduation in four years. Lafayette engineering faculty lead semester-long programs tailored to engineering majors in Bremen, Germany, and Madrid, Spain.

Lafayette chemical engineers meet with success beyond our campus. There is a 90 percent placement rate for all graduates within 12 months of graduation including a high rate of placement among premier employers such as ExxonMobile, Air Products and Chemicals, DuPont, BASF, and many others. Students continuing for advanced study enroll in top graduate programs, often supported by prestigious fellowships and awards. National Science Foundation Graduate Research Fellowship winners from Lafayette ChBE include Lauren Sefcik (2004), Gabriella Engelhart (2005), Scott Crown (2010), Ashley Cramer (2010), Melissa Gordon (2011), and Ashley Kaminski (2013).

FACULTY AND STAFF

Having grown from only one professor of chemical engineering in 1916, to five tenure track faculty in 1980, Chemical and Biomolecular Engineering (ChBE) at Lafayette now has nine tenure-track lines in the department. These include:

- *James K. Ferri, (department head and James T. Marcus 1950 Professor), Ph.D. chemical engineering, The Johns Hopkins University; interfacial phenomena, stability of disperse systems, additive manufacturing*
- *Lauren S. Anderson, associate professor, Ph.D. biomedical engineering, University of Virginia; tissue engineering, biomaterials, cell-substrate interaction*
- *Christopher R. Anderson, assistant professor, Ph.D. biomedical engineering, University of Virginia; molecular imaging, protein expression, and controlled drug delivery*
- *Polly R. Piergiovanni, professor, Ph.D. chemical engineering, University of Houston; biochemical engineering, pedagogical innovation*
- *James P. Schaffer, professor, Ph.D. mechanical engineering, Duke University; composite materials, non-destructive evaluation, engineering pedagogy*
- *Michael J. Senra, assistant professor, Ph.D. chemical engineering, University of Michigan; cold flow properties of petroleum, biofuel crystallization*
- *Lindsay Soh, assistant professor, Ph.D. chemical and environment engineering, Yale University; sustainable energy, biofuel production.*

In addition, the department is presently searching to fill two tenure-track faculty positions with a focus in advanced materials and manufacturing, energy and the environment, or micro nanofabrication.

CONCLUDING REMARKS

As we draw near to the completion of nearly a century of chemical engineering at Lafayette, the department continues to build on its strong tradition and reputation of excellence. We welcome you to contact us to find out more about the exciting developments at Lafayette College in ChBE.

ACKNOWLEDGMENTS

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